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MAIN PATTERNS OF VARIABILITY IN BEECH TREE-RING CHRONOLOGIES FROM DIFFERENT SITES IN SLOVENIA AND THEIR RELATION TO CLIMATE

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Abstract

Fourteen local tree-ring chronologies of beech (*Fagus sylvatica* L.) from different sites in Slovenia, elevations 300-1,415 m a.s.l., were constructed. Basic statistics of the chronologies (raw, standard and residual), climatic influence on tree growth, and growth variability among the sites are presented in the article. Dendroclimatological analysis showed that summer (particularly June) temperatures have negative and precipitation positive effect on tree-ring widths of beech on eleven sites in central, SE and SW Slovenia. The beech from highly elevated site in the Julian Alps above Tolmin (elevation 1200-1,450 m) showed positive response to summer temperatures. The whole variability in studied beech chronologies can be resumed in three sources of variation (principal components - PC): (PC_1) response of trees to June climate, (PC_2) altitude, and (PC_3) biogeographical differences.

Key words: beech, *Fagus sylvatica*, Slovenia, dendrochronology, tree-rings, local chronologies, climate

VARIABILNOST KRONOLOGIJ ŠIRIN BRANIK BUKVE Z RAZLIČNIH RASTIŠČ V SLOVENIJI GLEDE NA KLIMO

Izvleček

Avtorji članka so sestavili 14 lokalnih kronologij širin branik bukve (Fagus sylvatica L.) z različnih rastišč v Sloveniji (nadmorske višine 300-1415 m). Podajajo osnovno statistiko za različne verzije kronologij (kronologije širin branik, ARSTAN standard, ARSTAN residual), vpliv klime na variabilnost širin branik in variabilnost med rastišči. Dendroklimatološke analize so pokazale, da imajo poletne (posebno junijske) temperature negativen, padavine pa pozitiven vpliv na širine branik na 11 raziskanih rastiščih iz osrednje, JV in JZ Slovenije. Širine branik bukev z zgornje gozdne meje v Julijskih Alpah nad Tolminom (nadmorska višina 1200-1450 m) kažejo pozitiven odziv na temperature v času vegetacijske dobe. Analiza osnovnih komponent je pokazala, da razlike med rastišči lahko pripišemo trem komponentam: (PC_1) odzivu na junijsko klimo, (PC_2) nadmorski višini in (PC_3) fitogeografski regiji.

Ključne besede: bukev, Fagus sylvatica, Slovenija, dendrokronologija, širine branik, lokalne kronologije, klima

UVOD
INTRODUCTION

European beech (*Fagus sylvatica* L.) is the basic structural element of Slovenian forests. It grows in most forest associations from the lowlands up to the high mountains (MARINČEK 1987). It forms more than one third of the wood stock and its proportion is still increasing (BRUS 2005). It has recently been reported that future competitiveness of beech might be considerably reduced due to climate change (e.g. GEßLER *et al.* 2007) or that the changing climate might even cause a retreat of beech populations (e.g. JUMP / PEÑUELAS 2006). For Slovenia, the climate change scenario predicts a rise in temperature and more uneven distribution of precipitation associated with more frequent droughts and extreme rainfall events (BERGANT / KAJFEŽ-BOGATAJ 2005). This might affect the survival of beech, particularly on more extreme and marginal sites (e.g. DIACI 2007).

Wood forming capacity is an important indicator of tree physiology. Therefore long-term tree-ring chronologies are frequently used to evaluate current and past relationships of growth and climate in different tree species and bioclimatological units, and to estimate future prospects and possible ecological risks associated with climate change (e.g. SCHWEINGRUBER 1989). The beech is appropriate for dendroecological tree-ring studies (e.g. SCHWEINGRUBER 1990). Due to its frequency and ability to grow on sites of wide ecological variability, networks of beech tree-ring chronologies have been developed in different parts of Europe (e.g. BIONDI 1992, ROZAS 2001, DITTMAR / ZECH / ELLING

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2003, LEBOURGEOIS *et al.* 2005, PIOVESAN *et al.* 2005). Among others, it was found that the longevity of beech can exceed 500 years (PIOVESAN *et al.* 2003), which makes it even more suitable for long-term dendrochronological studies.

Tree-ring studies of beech in Slovenia have been in the last years part of different projects of the Department of Wood Science and Technology. Recently completed graduation theses contributed to the construction of local chronologies of trees (RUTAR 2003, NEKIČ 2005, ERCEK 2006, BERDAJS 2008), their prolongation with mean curves of historical buildings (KOBE 2005, ERCEK 2006), and generally contributed to our knowledge of wood formation (PRISLAN 2007).

Tree-ring data from Slovenian beech sites have also been employed to study bioclimatological units in the Eastern Alps (DI FILIPPO *et al.* 2007). They also proved to be useful to put the studies of wood formation within one growth period into long-term context (ČUFAR / PRISLAN / GRIČAR 2008, ČUFAR *et al.* 2008c).

The purpose of this study is to present the current stand of beech chronologies of the Department of Wood Science and Technology, to describe their main characteristics and their relation to climate, as well as to evaluate the differences among them. This would help to use them in different future studies with different aims.

MATERIALS AND METHODS
MATERIAL IN METODE

STUDY AREA AND WOOD FOR TREE-RING RESEARCH
VZORČNE LOKACIJE IN LES ZA ANALIZE ŠIRIN BRANIK

The samples for local beech tree-ring chronologies originated from old-grown trees at various locations: (1) Brezova Reber, (2) Gorjanci, (3) Čermošnjice, (4) Senovo, (5, 6) SE of Celje (two locations), (7) Cinkov Rog, (8) Knežja Lipa, (9) Kočevska Reka, (10) Draga, (11, 12, 13) surroundings of Tolmin (three locations), (14) Panška Reka near Ljubljana, (15) Mašun, (16) Pivka jama, and (17) Mokronog, Jelševec (Figure 1, Table 1). Analyses were performed on discs taken from tree stems (1-4 m above ground) during regular harvesting in the 2001-2007 period.

DENDROCHRONOLOGICAL ANALYSES
DENDROKRONOLOŠKE ANALIZE

Tree-ring widths were measured to the nearest 0.01 mm using TSAP/X and TSAP-Win programmes for data acquisition. The tree-ring series were visually and statistically cross-dated and compared with each other by calculating the t_{BP} (t-value after BAILLIE / PILCHER 1973) using TSAP/X and TSAP-Win. We checked the intercorrelation among the tree-ring series of individual trees and finally assembled them into a local chronology for each location. Eventually, we calculated three versions of each chronology, a non-detrended, raw-data, and a detrended standard and residual chronology using the program ARSTAN (HOLMES 1994). The agreement among the chronologies was also checked by calculating the $t_{BP.}$

TREE-RING WIDTHS AND CLIMATE
ŠIRINA BRANIK IN KLIMA

The climatic influence on tree growth was studied using residual versions of the chronologies obtained by ARSTAN program (HOLMES 1994). Hereby, the individual raw tree-ring series were standardized to remove the age-related growth trends and potential disturbance or competition effects in mean ring widths. We applied a two-step procedure as recommended by COOK and PETERS (1997). First, the long-term trend was removed by fitting a negative exponential function or a regression line to each tree-ring series. Second, a more flexible detrending was done by a cubic smoothing spline with a 50% frequency response of 60 years to filter-out the effect of localized potential disturbance events and then reduce further non-climatic variance in tree-ring series. Then, autoregressive modelling of the residuals and a bi-weight robust estimation of the mean were applied (COOK / PETERS 1997).

The meteorological data used were the monthly high-resolution grids of mean temperature and precipitation for the 1901-2000 period from CRU TS 1.2 that is publicly available (http://www.cru.uea.ac.uk/) (MITCHELL et al. 2004). This database is constructed with a 10 minute resolution for the whole Europe, also including some territories from the surrounding areas; the dataset covers 11ºW to 32ºE longitude and 34ºN to 72ºN latitude. For each location of a chronology, we used the closest grid-point from this database.

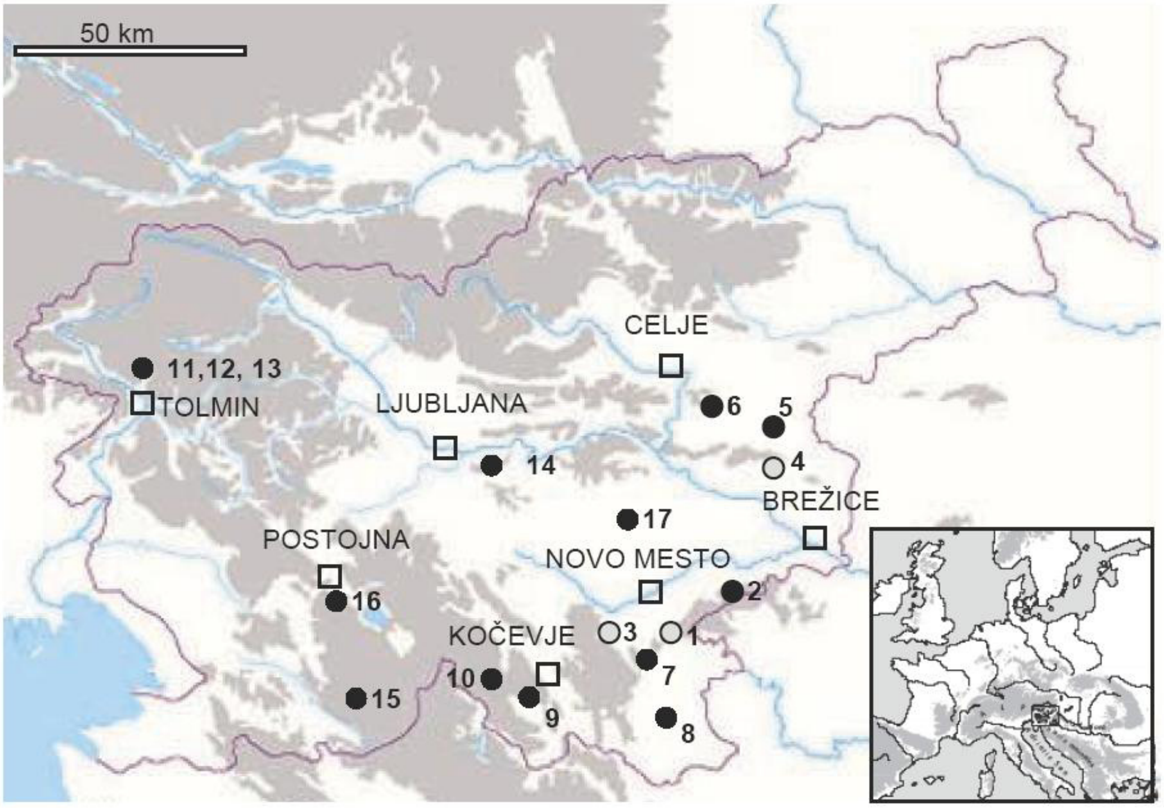

Fig. 1: Map of Slovenia with investigated beech sites (circles) from different forest districts (squares). Full circles show the sites where local chronologies have been constructed; insert shows the location of Slovenia within Europe. See also Table 1. Map: Scientific Research Centre of the Slovenian Academy of Sciences and Arts.

Slika 1: Zemljevid Slovenije z raziskanimi sestoji bukve (krogi) v različnih območnih enotah Zavoda za gozdove Slovenije (kvadrati). Ploskve, za katere so bile sestavljene lokalne kronologije širin branik, so označene s polnimi krogi. Prim. preglednico 1. Zemljevid: ZRC SAZU.

Climate-growth relationships were calculated using the DendroClim2002 program through correlation function analysis (BIONDI / WAIKUL 2004), whereby the residual version of the tree-ring chronology was the dependent variable and the monthly mean temperatures and the monthly sums of precipitation for each biological year from the previous September to the current September were the regressors. The program applies a bootstrap process (GUIOT 1991) to assess the statistical significance of the correlation coefficients.

COMMON VARIABILITY IN TREE-RING CHRONOLOGIES
SKUPNA VARIABILNOST KRONOLOGIJ ŠIRIN BRANIK

The main modes of common growth variability among stands were represented by principal component (PC) scores (DI FILIPPO *et al.* 2007). Component loadings (eigenvectors), which display the pattern of association of chronologies with each component, were employed to detect groupings in the tree-ring network. Selection of PCs was guided by Kaiser's Rule (KAISER 1992).

The spatial extent of the common signals was investigated by correlating PC scores with each local beech standard chronology. Thereafter, we looked for explanation of these different sources of variability by comparing the obtained loading components of each significant PC with general characteristics of each site of the chronology (e.g. altitude, climate, and distance from the sea).

RESULTS AND DISCUSSION
REZULTATI IN RAZPRAVA

THE CHRONOLOGIES
KRONOLOGIJE

We constructed 14 local chronologies based on at least 5 tree-ring series each. On 3 sites, the wood contained growth anomalies, therefore we could not build a chronology (Table 1). The basic statistics for raw non-detrended and detrended

Table 1: Description of beech locations (see also Figure 1).

Preglednica 1: Podatki o bukovih ploskvah (prim. sliko 1).

Nr. *Št.*	Code *Šifra*	Location *Naziv lokacije*	No. of trees* *Število dreves**	Altitude (m) *Nadmorska višina (m)*	Latitude (N) *Zemlj. širina (S)*	Longitude (E) *Zemlj. dolžina (V)*
1	BRE	Brezova Reber**	5	300-600	45.68º	15.21º
2	GOR	Gorjanci	16	300-600	45.76º	15.29º
3	CER	Čermošnjice**	5	300-600	45.66º	15.09º
4	SEN	Senovo**	5	300-600	46.01º	15.50º
5	CEA	Celje A	5	300-600	46.08º	15.54º
6	CEB	Celje B	5	300-600	46.11º	15.37º
7	CRO	Cinkov Rog	7	1000	45.70º	15.01º
8	KLI	Knežja Lipa	7	531	45.55º	15.00º
9	KRE	Kočevska Reka	7	568	45.56º	14.79º
10	DRA	Draga	7	750	45.63º	14.66º
11	TOA	Tolmin A, V Lazu	12	290-420	46.20º	13.73º
12	TOB	Tolmin B, Pod Zagonom	6	797-845	46.22º	13.75º
13	TOC	Tolmin C, Planina Kal	10	1240-1415	46.23º	13.77º
14	PAN	Panška Reka	14	400	46.00º	14.66º
15	MAS	Mašun	15	1000	45.63º	14.40º
16	PIV	Pivka jama	19	640	45.80º	14.16º
17	MOK	Mokronog, Jelševec	27	400	45.91º	15.20º

* Number of trees collected / *Število vzorčnih dreves*

** Tree ring chronology could not be constructed / *Kronologija širin branik ni bila sestavljena*

ARSTAN standard and residual chronologies is given in Table 2. The results show that the chronologies were from 83 to 271 years long and spanned the 1731-2007 period. The longest chronologies were constructed for locations 13, 10, 9 and 2 (Tolmin C - Planina Kal, Draga, Kočevska Reka and Gorjanci) (Figure 2). The oldest trees were found at the sites 13, 10 and 9, where some of them aged 250 years or more. In raw chronologies, the mean ring widths varied from 1.1 to 3.0 mm and the standard deviation was 0.40 to 1.04. The mean sensitivity (MS) from residual chronologies varied from 0.15

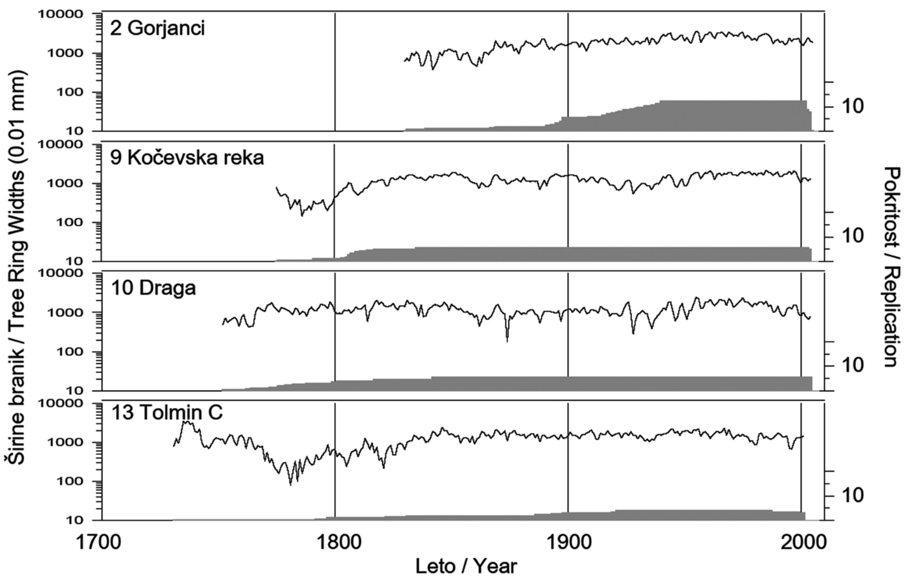

Fig. 2: The longest tree-ring chronologies (raw versions) and their replication (i.e. number of trees used to build them).

Slika 2: Najdaljše kronologije širin branik (neindeksirane verzije) in njihova pokritost (število dreves vključenih v kronologijo).

to 0.26. These values were higher than in the regional oak chronology of SE Slovenia, where MS was only 0.11 (ČUFAR *et al.* 2008b). They indicate that the beech (in Slovenia) is more sensitive to climate variation than oak. The MS values of Slovenian beech chronologies are at the same time mostly lower than in beech from other parts of Europe (e.g. DITTMAR / ZECH / ELLING 2003, DI FILIPPO *et al.* 2007).

Serial first-order autocorrelation (AC1) was high in raw chronologies indicating a significant long-term age trend in ring-width series. After detrending, the AC1 still remained significant in standard chronologies indicating also a significant influence of a previous ring width on the current one. The autocorrelation was successfully removed in residual chronologies (see negligible $AC1_{res}$ in Table 2).

The signal strength (SS) calculated with ARSTAN showed that only the residual chronologies of the sites 2, 13, 14, 15 and 17 had SS greater than 0.85 and could therefore be considered representative for dendroclimatological analysis. These chronologies were based on 10 trees or more.

Despite the insufficient SS and replication at the other 6 sites, we used all 14 chronologies to obtain an indication of how the beech at different sites in Slovenia responds to climate. Namely, the study presented here is the first one on response of beech tree-rings to climate in Slovenian sites and additional sampling and analyses are planned to improve and confirm the current results.

t-values (t_{BP}) calculated to test the similarity among the chronologies showed that tree-ring variation in beech from the central and southern parts of Slovenia is governed by a common factor (Table 3), for chronologies are considered to be similar when $t_{BP} \geq 4$ (e.g. LEVANIČ 1996). On the other hand, the chronologies from the surroundings of Tolmin showed nearly no similarity with the other ones. Poor replication of the chronologies from sites 11 and 12, and high elevation of the site 13 could possibly be among the main reasons for such results. It should be noted that the chronology from site 13 had been previously used in another study and that it agreed significantly with 3 beech chronologies from the high elevation Alpine sites in NE Italy (Paularo, Lateis) and in Austria (Hallstatt) (DI FILIPPO *et al.* 2007).

CLIMATE / GROWTH RELATIONSHIPS
KLIMA IN VARIIRANJE ŠIRIN BRANIK

Year to year tree-ring variation was negatively affected by June temperature and positively by June precipitation at

Table 2: Descriptive statistics of beech chronologies: time span and length (in years), number of trees used to build a chronology, mean ring width (mm), MS-mean sensitivity, STD-standard deviation, AC1 – autocorrelation 1st order. MS and AC1 are given for raw, standard (std) and residual (res) versions of the chronology.

Preglednica 2: Statistični podatki o bukovih kronologijah: razpon in dolžina (v letih), število vključenih dreves, srednja širina branik (mm), MS-srednja občutljivost, STD-standardni odklon, AC1 – avtokorelacija 1. reda. MS in AC1 so podani za neindeksirane kronologije širin branik (raw) ter za indeksirane standardne (std) in residual (res) verzije kronologij.

Raw chronology / *Kronologija širin branik*										ARSTAN chronologies *ARSTAN kronologije*			
										Standard		*Residual*	
No *Št.*	Code *Šifra*	Time span *Razpon*		Length *Dolžina*	No. of trees *Število dreves*	Ring width *Širina branik*	STD	MS_{raw}	$AC1_{raw}$	MS_{std}	$AC1_{std}$	MS_{res}	$AC1_{res}$
2	GOR	1830	2005	176	16	1.84	0.75	0.18	0.86	0.20	0.34	0.22	-0.0345
5	CEA	1840	2001	162	5	1.68	0.71	0.20	0.84	0.21	0.54	0.23	0.0435
6	CEB	1883	2001	119	5	1.82	0.50	0.15	0.75	0.15	0.53	0.18	-0.0215
7	CRO	1832	2004	174	6	2.47	0.71	0.22	0.54	0.20	0.29	0.24	-0.1259
8	KLI	1845	2004	160	6	1.67	0.71	0.23	0.77	0.22	0.48	0.25	-0.0250
9	KRE	1775	2004	230	7	1.13	0.47	0.14	0.91	0.16	0.53	0.16	0.0093
10	DRA	1752	2004	253	7	1.20	0.41	0.21	0.71	0.22	0.49	0.25	0.0010
11	TOA	1880	2001	122	8	2.00	0.97	0.17	0.90	0.17	0.31	0.21	-0.0117
12	TOB	1919	2001	83	6	3.00	1.06	0.17	0.86	0.18	0.15	0.19	-0.0352
13	TOC	1731	2001	271	10	1.24	0.57	0.22	0.85	0.23	0.52	0.15	-0.0125
14	PAN	1873	2007	135	14	1.69	0.53	0.18	0.76	0.18	0.51	0.26	0.0963
15	MAS	1844	2007	164	24	1.44	0.40	0.15	0.76	0.16	0.34	0.16	0.0001
16	PIV	1840	2007	168	8	1.73	0.41	0.18	0.59	0.18	0.33	0.19	-0.0131
17	MOK	1854	2007	154	27	1.79	0.47	0.17	0.70	0.17	0.45	0.20	-0.0647

Table 3: Cross-dating parameters (t_{BP}) of raw data chronologies. Only statistically significant values of $t_{BP} \geq 4$ are given.

Preglednica 3: Kazalniki ujemanja (t_{BP}) kronologij širin branik. Podani so samo statistično značilni kazalniki $t_{BP} \geq 4$.

No *Št.*	Code *Šifra*	2 GOR	5 CEA	6 CEB	7 CRO	8 KLI	9 KRE	10 DRA	11 TOA	12 TOB	13 TOC	14 PAN	15 MAS	16 PIV
5	CEA													
6	CEB	5.5	6.1											
7	CRO	7.7	4.7	5.4										
8	KLI	6.7	5.6	5.5	8.8									
9	KRE		5.7	4.3	6.8	5.8								
10	DRA		5.0		9.8	5.8	9.8							
11	TOA													
12	TOB													
13	TOC						4.2							
14	PAN	5.7	6.5	4.3	6.3	5.4	4.5	5.3						
15	MAS		2.6	4.4	7.0	4.4	6.8	8.4				5.8		
16	PIV	5.7	4.9	5.7	7.1	6.2	5.5	7.4				4.8	7.1	
17	MOK	6.8	9.4	7.3	9.2	8.6	4.2	5.0				10.7	5.8	6.5

Chronology codes / *Oznake kronologij*: 2 GOR, Gorjanci; 5, CEA, Celje A; 6, CEB, Celje B; 7, CRO, Cinkov Rog; 8, KLI, Knežja Lipa; 9, KRE, Kočevska Reka; 10, DRA, Draga; 11, TOA, Tolmin A; 12, TOB, Tolmin B; 13, TOC, Tolmin C; 14, PAN, Panška Reka; 15, MAS, Mašun; 16, PIV, Pivka jama; 17, MOK, Mokronog.

11 sites (2, 5, 6, 7, 8, 9, 10, 14, 15, 16, and 17) (Figure 3). Slightly less pronounced but still consistent was the positive effect of July precipitation and negative effect of July temperature. May or August precipitation and temperature had in some cases significantly positive and negative effects as well. Precipitation and temperatures of previous autumn and winter months in some cases affected tree-ring variability, too, but their influence differed from site to site.

June is an important month for growth of plants due to the longest photoperiod. As evaluated by ČUFAR *et al*. (2008a), June weather conditions in Slovenia can differ considerably from year to year. Mean precipitation and mean temperature in June are around 37 mm and 20°C in dry years, 236 mm and 16°C in moist and cold years, and 129 mm and 18°C in normal years.

Recent studies on wood formation in beech at site 14 near Ljubljana showed that the highest monthly amount of wood, i.e. 35% of the entire tree-ring, was produced in June (ČUFAR/ PRISLAN / GRIČAR 2008, ČUFAR *et al.* 2008c). Other studies demonstrated that June conditions have a great effect on wood formation in *Picea abies* and *Abies alba* from different sites in Slovenia (GRIČAR 2007) and on trees from many other sites in Europe and North America (ROSSI / DESLAURIERS / ANFODILLO 2006). June conditions also proved to have crucial and temporally stable effect on tree-ring variation in oak from SE Slovenia (ČUFAR *et al.* 2008b). The temperature and precipitation effect on tree-ring variation in oak was proved to be so significant and stable in time, that it could be used for reconstruction of June conditions in SE Slovenia for the last 500 years (ČUFAR *et al.* 2008a).

Moist and not too hot June conditions therefore positively influence tree-ring widths in beech and other tree species. June conditions are also crucial for agriculture, for example maize and other grain crops as well as for many other cultivated plants (e.g. AŽNIK / KAJFEŽ-BOGATAJ 1982).

Positive effects of precipitation and negative effect of temperatures in May, July and August indicate that the trees can use favourable conditions for increased wood production not only in June, but also in the period from May to August.

The climatic response of beech in Slovenia compared with that of SE Slovenian oak and beech from other European sites indicates that June climatic conditions at our sites are most likely optimal for beech growth and contribute less to inter-annual tree-ring variation than in other regions.

The response of trees to climate at the high elevation site 13 differs from all other sites. The tree-ring variation here is positively affected by late spring and summer temperatures, particularly by May temperature. This site has with its 1,240-1,415 m a.s.l. the highest elevation of all sites (Table 1) and the beech grows here at its altitudinal limit. At such elevation the growing season begins later than at lower elevated sites, most likely in May, and the beech here is more frequently

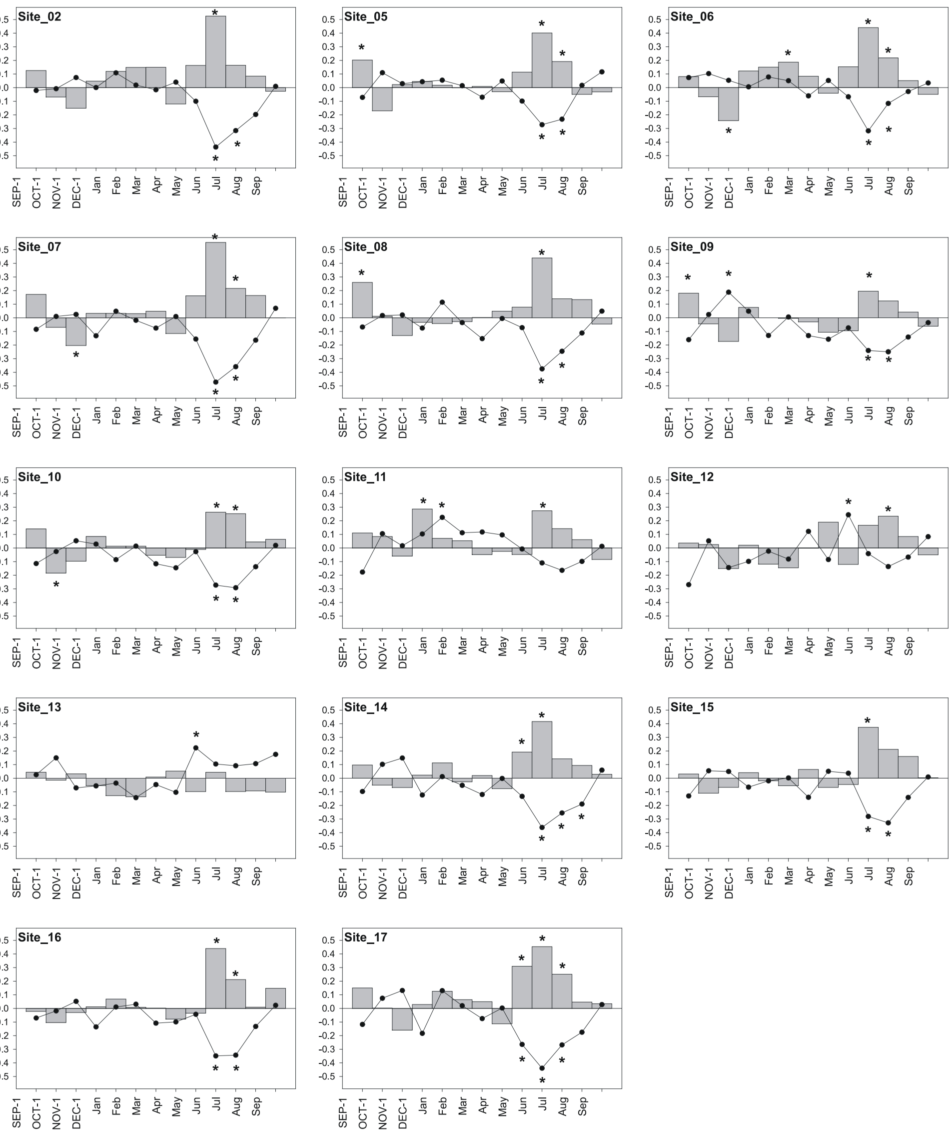

Fig. 3: Bootstrap correlation values calculated for the residual chronologies of beech from different sites in Slovenia and monthly temperatures (line) and precipitation (bars) from previous to current September (1901-2000 period); stars indicate significance at 95% level.

Slika 3: Korelacijski faktorji bootstrap za bukove kronologije ARSTAN residual z različnih rastišč v Sloveniji ter povprečne mesečne temperature (črte) in skupne mesečne padavine (stolpci) od preteklega do tekočega septembra (obdobje 1901-2000); zvezdice označujejo statistično značilnost pri meji zaupanja 95 %.

Chronology codes / *Oznake kronologij*: Site 2 GOR, Gorjanci; Site 5, CEA, Celje A; Site 6, CEB, Celje B; Site 7, CRO, Cinkov Rog; Site 8, KLI, Knežja Lipa; Site 9, KRE, Kočevska Reka; 10, DRA, Draga; Site 11, TOA, Tolmin A; Site 12, TOB, Tolmin B; Site 13, TOC, Tolmin C; Site 14, PAN, Panška Reka; Site 15, MAS, Mašun; Site 16, PIV, Pivka jama; Site 17, MOK, Mokronog.

affected by late-frost damage (DITTMAR *et al.* 2006, DI FILIPPO *et al.* 2007). All this could help to explain why the late spring and summer warmth promotes the tree-ring growth.

Since most of the beech sites elevated up to 1,000 m a.s.l. showed negative response to summer drought and high temperatures, and the high elevated site 13 showed an opposite pattern (i.e. positive response to summer warmth), the transition from one pattern to another possibly occurs at the elevation from 1,000 to 1,200 m a.s.l. This should also be confirmed in the near future by additional studies.

Principal component (PC) analysis indicates that the whole variability in presented beech chronologies can be resumed in three significant sources of variation, i.e. principal components PC_1, PC_2 and PC_3. PC_1 explains 49% of total variability, showing that an important common signal exists among the chronologies. It also explains more than 50% of variability in all chronologies except the ones from the surroundings of Tolmin, sites 11, 12 and 13 (Figure 4 a). At sites 2, 5, 6, 7, 8, 9, 10, 14, 15, 16 and 17, this common signal seems to be related to common sensitivity to June temperature and precipitation (Figure 4 b).

PC_2 explains 11% of total variability, showing that another important common signal exists among the chronologies. Its importance greatly varies among the sites (Figure 4c). It highly correlates with chronology at site 13, but is also relatively important at sites 15, 9, 10, 5 and 12. This common signal seems to be at least partially explained by altitudinal gradient (Figure 4d).

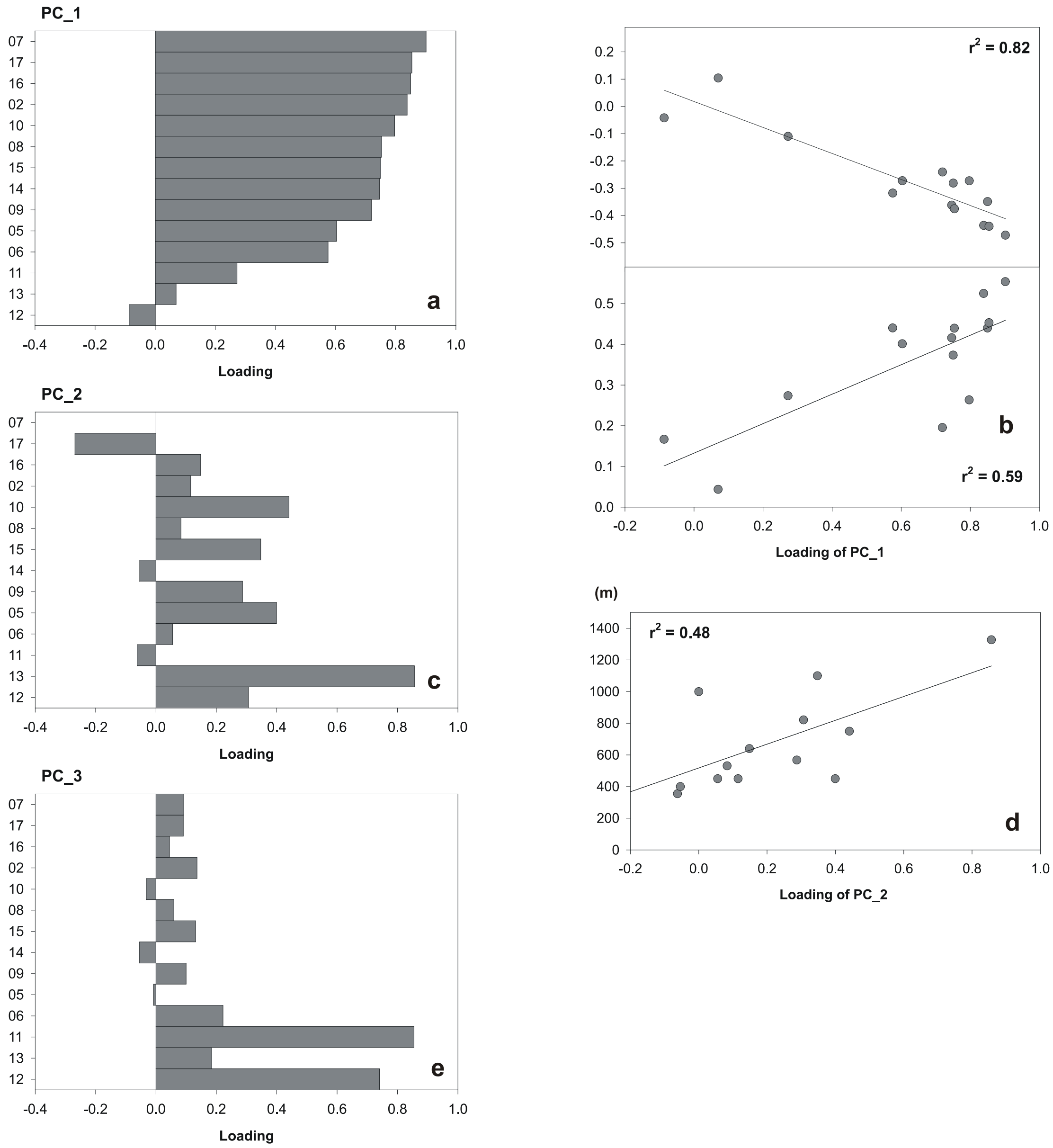

Fig. 4: Principal component (PC) analysis for eleven sites in Slovenia: (a, c) loading of PC_1 and its correlation with June temperature and precipitation, (b, d) loading of PC_2 and its correlation with altitude, (e) loading of PC_3.

Slika 4: Analiza osnovnih komponent (PC) za enajst rastišč v Sloveniji: (a, c) vpliv PC_1 ter njena korelacija z junijskimi temperaturami in padavinami, (b, d) vpliv PC_2 in njena korelacija z nadmorsko višino, (e) vpliv PC_3.

Chronology codes / *Oznake kronologij*: 2 GOR, Gorjanci; 5, CEA, Celje A; 6, CEB, Celje B; 7, CRO, Cinkov Rog; 8, KLI, Knežja Lipa; 9, KRE, Kočevska Reka; 10, DRA, Draga; 11, TOA, Tolmin A; 12, TOB, Tolmin B; 13, TOC, Tolmin C; 14, PAN, Panška Reka; 15, MAS, Mašun; 16, PIV, Pivka jama; 17, MOK, Mokronog.

PC_3 explains 7.5% of total variability, but is important only locally (merely at sites 11 and 12) (Figure 4e). This result can be explained with location of the chronologies in different biogeographical regions with different climate conditions. PC_3 may be affected by the distance from the sea (c.f. DI FILIPPO *et al.* 2007). The sites 11, 12 and 13 are located on the border between the Sub-Mediterranean and Alpine phytogeographical areas (MARTINČIČ *et al.* 1999). These Alpine sites are connected to the 50 km distant Adriatic coast by the Soča river valley and are therefore strongly affected by the interference between the Sub-Mediterranean and Alpine climatic influence.

CONCLUSIONS
SKLEPI

The results indicate that generally known differences among beech populations growing at various sites, forest associations and elevations in Slovenia are also reflected in response of their tree-rings to climate.

The tree-ring variation in beech at eleven sites in central, SE and SW Slovenia proved to be negatively affected by June temperature and positively by June precipitation. Similar but less pronounced effect may also have July, May and August conditions.

The climatic response of beech in SE and SW Slovenia compared with that of beech from other European sites indicates that June climatic conditions here are optimal for beech growth and contribute less to inter-annual tree-ring variation than in other European regions.

The response to June conditions mentioned above cannot be confirmed for beech from sites above Tolmin (11, 12, 13). At site 13, elevation 1,200-1,450 m a.s.l., the beech responds positively to late spring/summer temperatures.

The variation of beech tree-rings can be explained by three sources of variation, i.e. three principal components (PC). PC_1 is mainly explained by June climatic conditions, PC_2 by altitude and PC_3 possibly by climatic differences among phytogeographical regions.

The present study will hopefully contribute to better understand the physiology of beech as well as its possible flexibility and risks related to climate change in different bioclimatological units.

SUMMARY
POVZETEK

Bukev (*Fagus sylvatica*) v Sloveniji uspeva v večini gozdnih združb od nižin do visokogorij (MARINČEK 1987). Njen delež presega tretjino gozdne zaloge in še narašča (BRUS 2005). V Evropi je v zadnjem času slišati svarila, da bi kompetitivnost bukve lahko ogrozile klimatske spremembe (JUMP / PEÑUELAS 2006, GEßLER *et al.* 2007). Ob napovedanem scenariju klimatskih sprememb v Sloveniji (BERGANT / KAJFEŽ-BOGATAJ 2005) bi te lahko ogrozile bukev tudi pri nas, in to najprej na bolj ekstremnih rastiščih in na robu njenega areala (DIACI 2007).

Količina biomase, ki jo drevo investira v debelinski prirastek (nastanek branik v lesu), je dober kazalec fiziologije drevja, nastajanje lesa pa je med drugim odvisno od klimatskih razmer. Zato so pomembne časovne vrste širin branik, ki so med drugim pogosto uporabljene za študij različnih dejavnikov na rast drevja v različnih bioklimatskih enotah. Pomembne so tudi za napovedovanje bodočih učinkov škodljivih dejavnikov, kamor spadajo tudi klimatske spremembe. Bukev je primerna za takšne dendroekološke študije (npr. SCHWEINGRUBER 1990), zato so v različnih delih Evrope začeli s sestavljanjem omrežij kronologij širin branik za različne potrebe (BIONDI 1992, ROZAS 2001, DITTMAR / ZECH / ELLING 2003, PIOVESAN *et al.* 2003, PIOVESAN *et al.* 2005, LEBOURGEOIS *et al.* 2005). Med drugim so ugotovili tudi to, da je bukev bolj dolgoživa, kot so domnevali, in da je mogoče najti tudi do 500 let stara drevesa.

Na Oddelku za lesarstvo Biotehniške fakultete v Ljubljani je bila raziskava širin branik pri bukvi vključena v različne projekte. V okviru diplomskih nalog je bilo sestavljenih več lokalnih bukovih kronologij (RUTAR 2003, NEKIČ 2005, ERCEK 2006, BERDAJS 2008), ukvarjali pa so se tudi s podaljšanjem kronologij z lesom iz zgodovinskih objektov (KOBE 2005, ERCEK 2006) in z nastankom lesa (PRISLAN 2007). Bukove kronologije širin branik iz Slovenije so bile uporabljene tudi za študij bioklimatskih enot v jugovzhodnih Alpah (DI FILIPPO *et al.* 2007). Uporabne so tudi, ko želimo kratkoročne študije nastanka lesa umestiti v dolgoročni okvir (ČUFAR / PRISLAN / GRIČAR 2008, ČUFAR *et al.* 2008c).

Namen pričujočega prispevka je predstaviti trenutno stanje razvoja kronologij širin branik bukve na Oddelku za lesarstvo, njihove značilnosti, njihov odziv na klimatske dejavnike ter razlike med kronologijami z različnih območij v Sloveniji, vse to z namenom, da bi podatke kronologij v prihodnje dopolnili in jih bolje uporabili za različne študije.

Les za raziskave smo pridobili iz dreves, posekanih med redno sečnjo. Les je izviral s 17 rastišč: (1) Brezova Reber, (2) Gorjanci, (3) Čermošnjice, (4) Senovo, (5, 6) jugovzhodno od Celja (dve lokaciji), (7) Cinkov Rog, (8) Knežja Lipa, (9) Kočevska Reka, (10) Draga, (11, 12, 13) nad Tolminom (V Lazu, Pod Zagonom, Planina Kal), (14) Panška Reka pri Ljubljani, (15) Mašun, (16) Pivka jama in (17) Mokronog, Jelševec.

Na kolutih vzorčnih dreves (višine v deblu 1- 4 m) smo izmerili širine branik, sestavili datirane krivulje širin branik glede na čas in s pomočjo programa ARSTAN sestavili več različic kronologij za vsako lokacijo (neindeksirano kronologijo širin branik ter indeksirano standardno in residual verzijo ARSTAN kronologij) (HOLMES 1994). Za študij zveze med širinami branik in klimo smo uporabili residual-verzijo kronologije, meteorološke podatke (povprečne mesečne temperature in mesečne količine padavin) iz mreže CRU TS 1.2 (http://www.cru.uea.ac.uk/) (MITCHELL *et al.* 2004) in program DendroClim2002 (BIONDI / WAIKUL 2004), ki uporablja postopek bootstrap (GUIOT 1991) za določanje statistične značilnosti korelacijskih koeficientov. Za ovrednotenje razlik med kronologijami z različnih rastišč smo uporabili analizo osnovnih komponent (DI FILIPPO *et al.* 2007). Za izbor osnovnih komponent (PC) smo uporabili Kaiserjevo pravilo (KAISER 1992).

Sestavili smo 14 lokalnih kronologij širin branik za nadmorske višine od 300 do 1415 m. Dendroklimatološke analize so pokazale, da imajo poletne (posebno junijske) temperature negativen, junijske padavine pa pozitiven vpliv na širine branik na enajstih raziskanih rastiščih iz osrednje, JV in JZ Slovenije. Širine branik bukev z zgornje gozdne meje v Julijskih Alpah nad Tolminom (nadmorska višina 1200-1450 m) pa v nasprotju z drugimi rastišči kažejo pozitiven odziv na temperature v času vegetacijske dobe (predvsem v maju). Analiza osnovnih komponent (PC) je pokazala, da razlike med rastišči lahko pripišemo trem komponentam: (PC_1) odzivu na junijsko klimo, (PC_2) nadmorski višini in (PC_3) fitogeografski regiji.

Rezultati potrjujejo, da splošno znane razlike med bukovimi rastišči lahko ovrednotimo tudi z zvezo med variabilnostjo širin branik in klimo.

Zanimiv je velik vpliv junijskih razmer na variiranje širin branik med leti. V članku diskutiramo o pomenu junijskih razmer za rast dreves in drugih rastlin. Nekoliko manj pomemben, a podoben vpliv kot junijske razmere imajo temperature in padavine v maju, juliju in avgustu. Ta ugotovitev se dopolnjuje z našimi raziskavami nastanka lesa pri bukvi s Panške reke pri Ljubljani, kjer smo ugotovili, da je v juniju 2006 nastalo več kot 35 % branike, kar je največji mesečni prirastek branike (ČUFAR/ PRISLAN / GRIČAR 2008, ČUFAR *et al.* 2008c).

Podoben pomen junijskih temperatur in padavin smo ugotovili tudi pri hrastih, predvsem gradnu (*Quercus petraea*) iz JV Slovenije (ČUFAR *et al.* 2008a, ČUFAR *et al.* 2008b), kjer so bile junijske razmere najpomembnejše za razlago medletne variabilnosti širin branik. Podobnost med kronologijami širin branik hrasta in bukve na osnovi rezultatov pričujočega sestavka lahko razložimo s podobnim odzivom bukve in hrasta na junijsko klimo (ČUFAR *et al.* 2008b).

Bukove kronologije (verzija residual) so imele srednjo odzivnost (ang. mean sensitivity) 0.15-0.26, kar je več kot pri hrastu iz Slovenije in manj kot pri večini bukovih kronologij iz Evrope (prim. DITTMAR / ZECH / ELLING 2003, DI FILIPPO *et al.* 2007). To nakazuje, da so pri bukvi širine branik bolj odvisne od klime kot pri hrastu in da so junijske razmere v Sloveniji optimalne za rast bukve in hrasta in bolj ugodne kot v drugih evropskih regijah, kjer so že opravili podobne raziskave.

Opisani odziv ne velja za rastišča nad Tolminom, kjer posebej bukev z zgornje gozdne meje na nadmorski višini 1200-1450 m kaže pozitiven odziv na temperature v času vegetacijske dobe.

Pričujoča študija naj bi pripomogla k boljšemu poznavanju fiziologije bukve in odvisnosti nastanka lesa od klime ter prednosti bukve in nevarnosti zanjo zaradi možnih sprememb klime v različnih bioklimatskih regijah.

Na lokacijah, kjer je bilo za sestavo kronologij uporabljenih manj kot 10 dreves, bi bilo treba opraviti dodatno vzorčenje in analize za potrditev predstavljenih rezultatov.

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